Carbon Dioxide-Free Hydrogen and Solid Carbon from Natural Gas Via Metal Salt Intermediates (DE-AR0001019)

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Project Vision

Hydrogen, carbon, heat and water from natural gas:
anywhere, profitably, efficiently, and without CO_2 emissions.

Total project cost:	$4.1M
Length	48 mo.

The Team

JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING

R&D

commercialization

ETCH

energy and power

Southern Company

CABOT

carbon

The ETCH Process

Natural gas is input and decomposed:

1. $CH_4 + 2NiCl_2(g) \rightarrow 2Ni + C + 4HCl$

   $\Delta H^o = -147\,kJ/mol_{CH_4}$

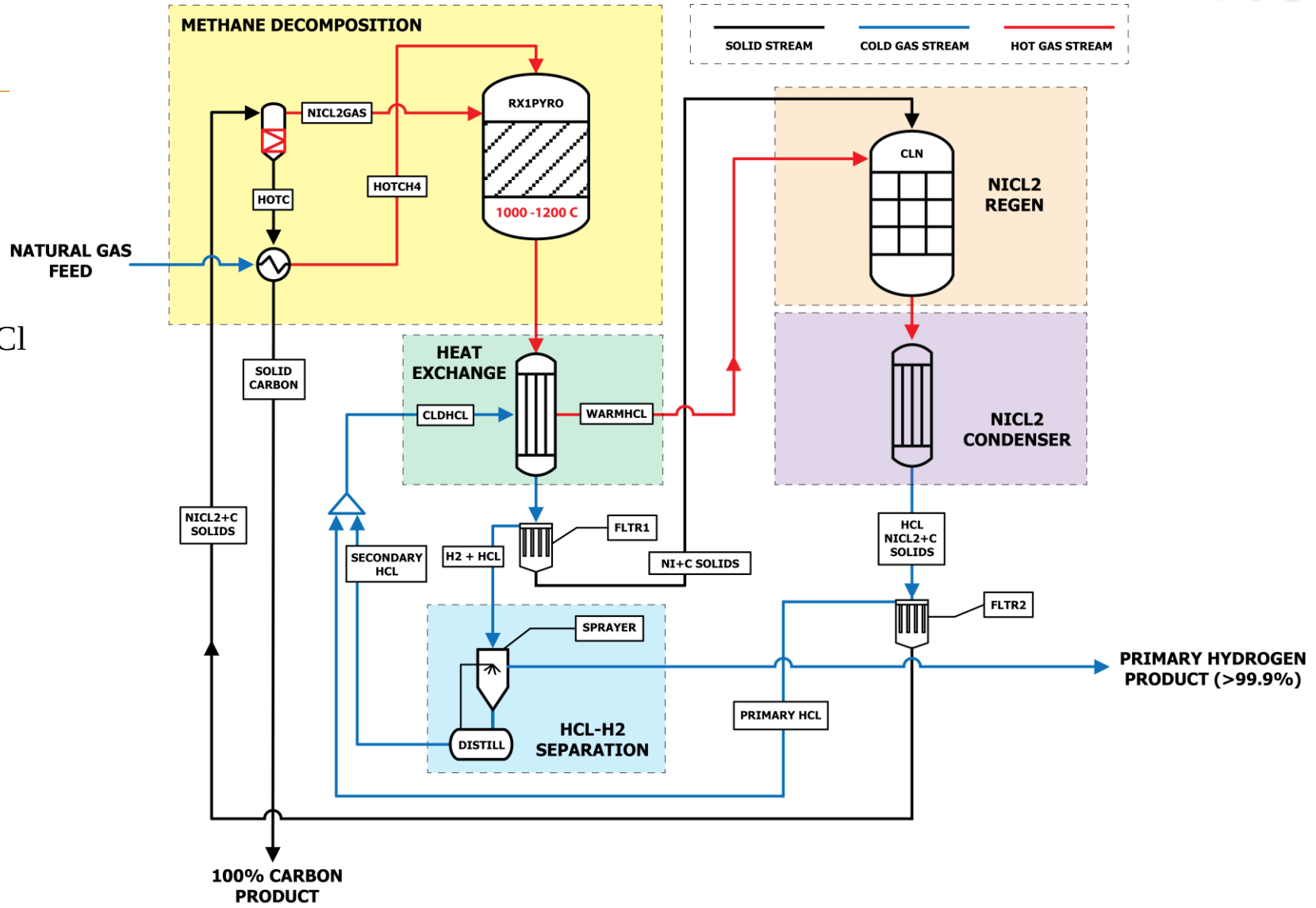
2. $CH_4 \rightarrow C + 2H_2$

   $\Delta H^o = 75\,kJ/mol_{CH_4}$

Nickel chloride regeneration:

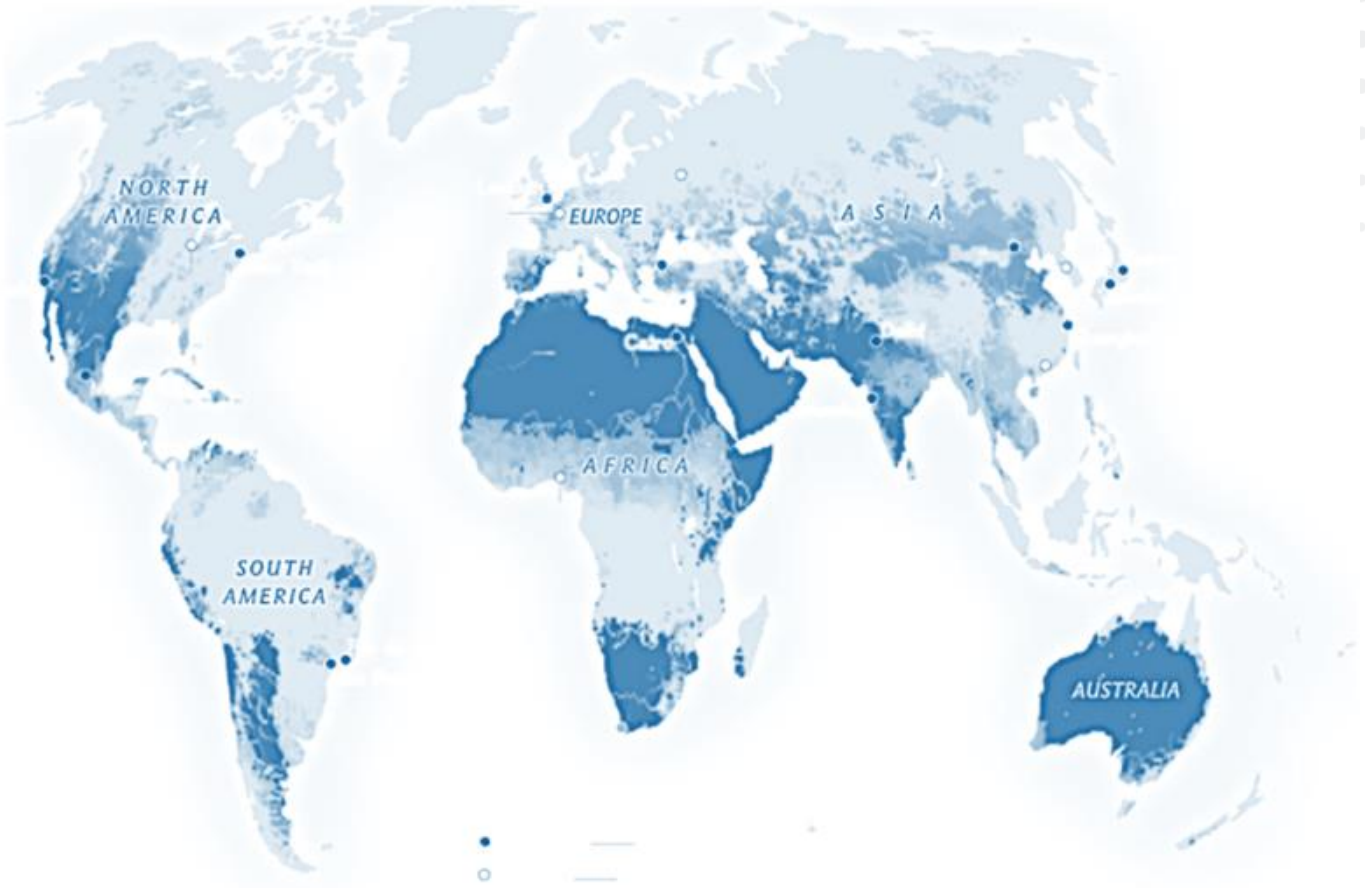
3. $Ni + 2HCl \rightarrow NiCl_2(g) + H_2$

   $\Delta H^o = 111\,kJ/mol_{Ni}$



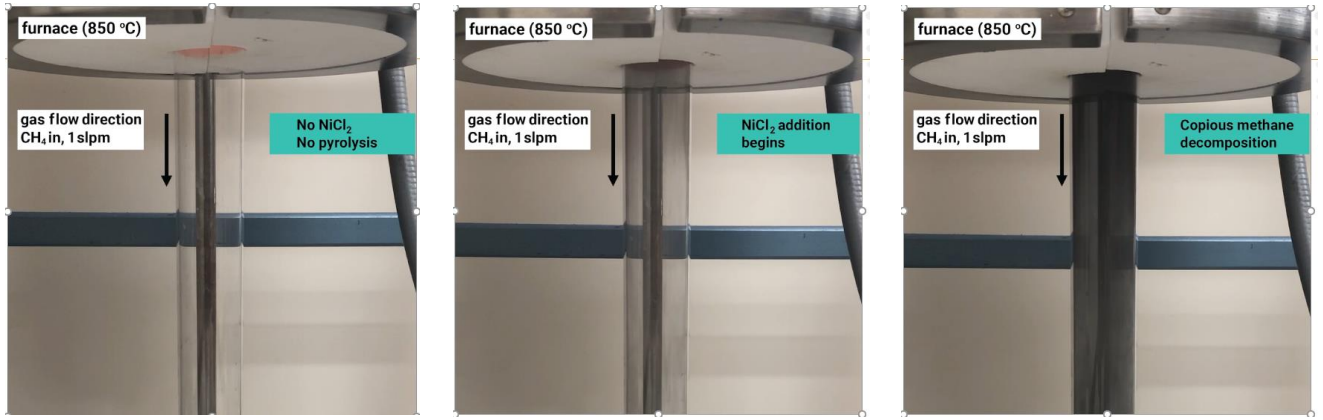
Exciting Aspects of the ETCH Process

- High conversion efficiency
  - Much more favorable than pyrolysis alone
  - Overcomes “hot wall” problem
- Water-free chemistry
- Flexibility with respect to input power
  - natural gas (3 kgCO2/kgH2)
  - renewable electricity (zero CO2)
  - hydrogen (zero CO2)
- Modular and geographically locatable anywhere
- Low-cost hydrogen (potentially < $1/kg)
- High purity carbon

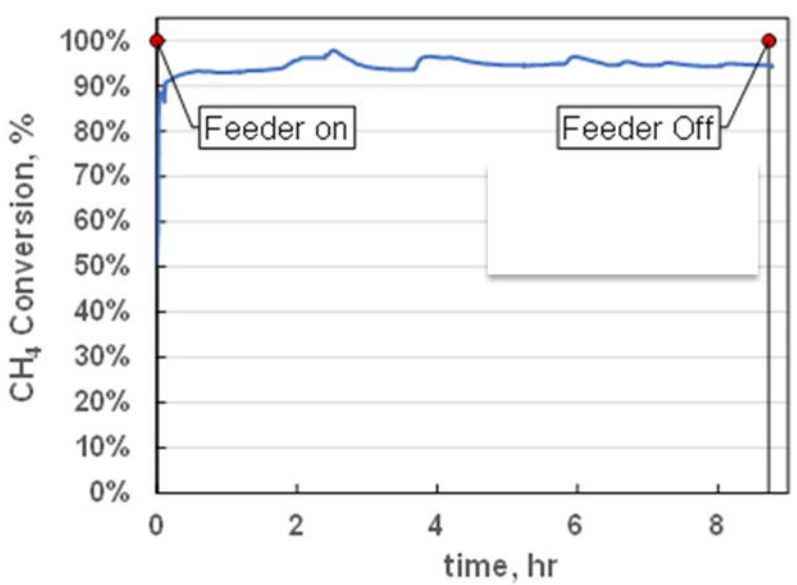


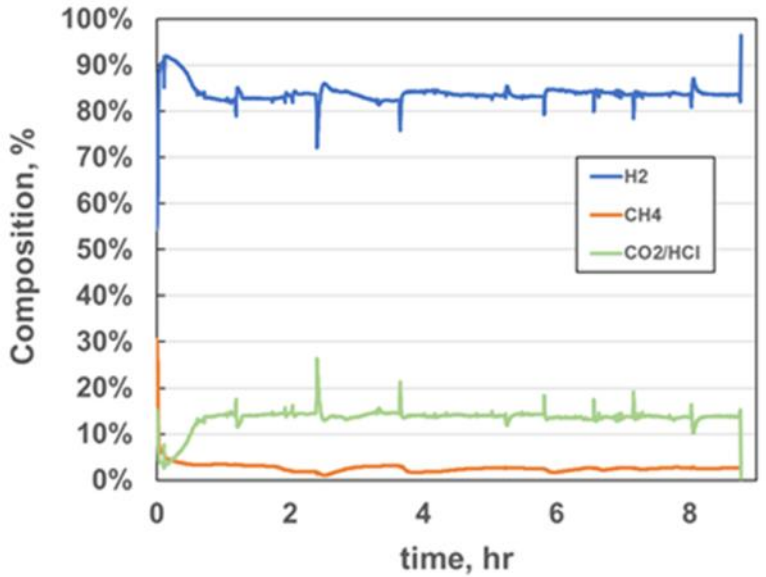
The ETCH Process in Action

- Reactor is co-fed with CH4 and NiCl2
- ~100% methane decomposition over 36” hot zone (different conditions than video)
- Free flowing powder
- No sidewall deposition



An example showing reaction efficiency, and model fidelity : 95% conversion over 8 hours at 1 lpm methane, 36” long reactor, 3.8 cm ID





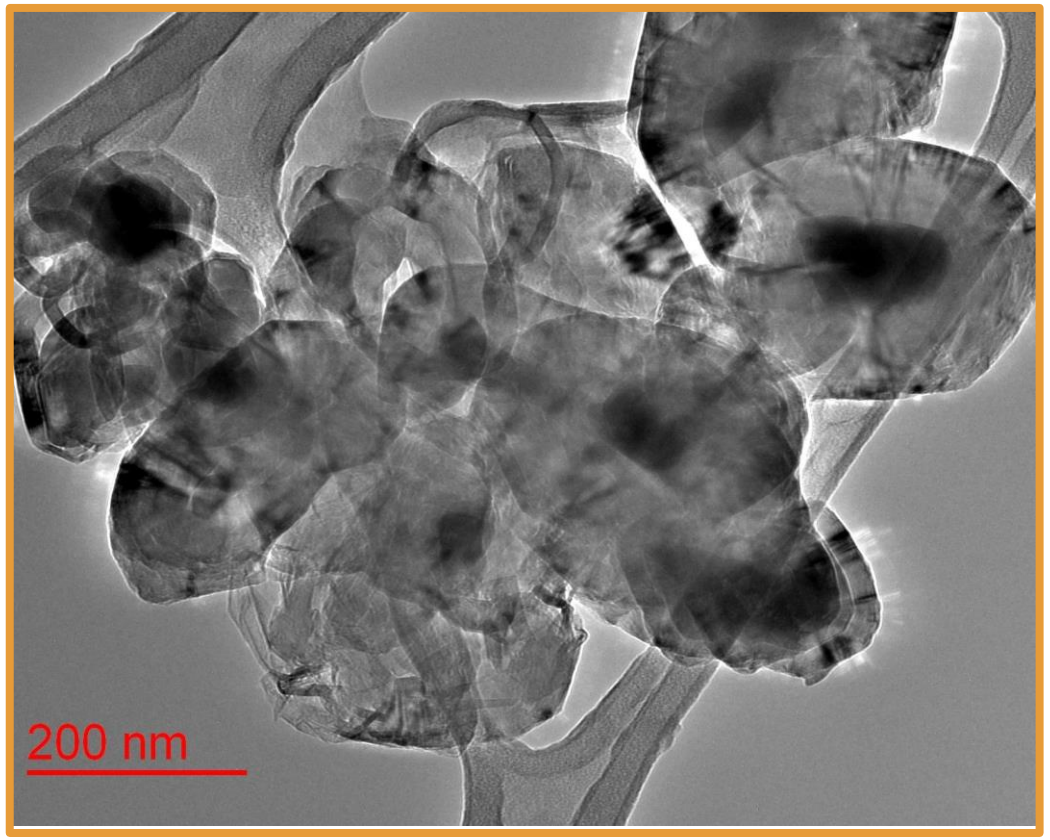
Conversion (left) and exit stream composition (right) versus time for 8-hour milestone run using 1.05 lpmCH4. Average conversion was 95% (dialed in), with no degradation in performance.

Expected mass and composition of Ni-C powder: 498 g (yield 468 g). Reaction model prediction: conversion (96%; actual 95%), H_2 (87%; actual 84%), CH_4 (2%; actual 2%), HCl (11%; actual 14%)

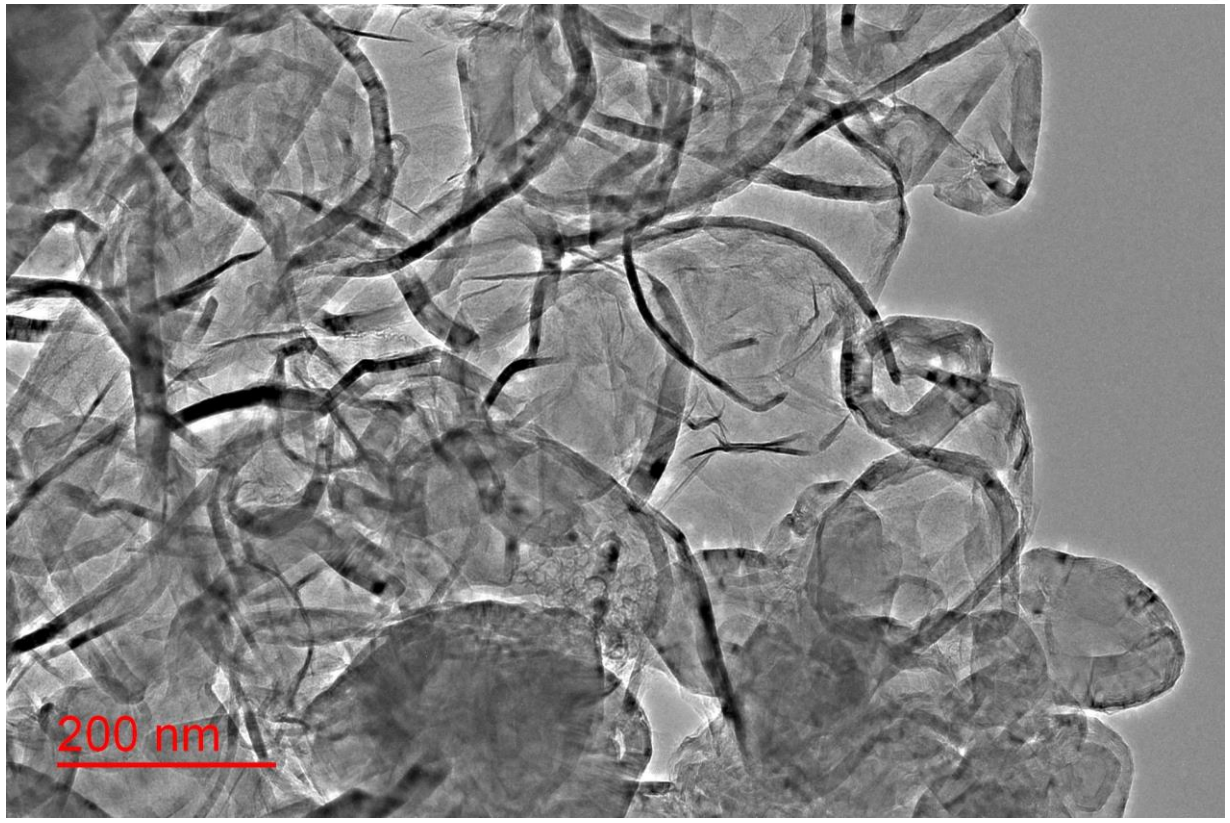
Carbon from the ETCH Process

- We have invented a method to recover metal from coked particles that is integrated into our process. Method is insensitive to the C:Ni ratio
- Sample carbons shows undetectable levels of metal by EDS; material is non-magnetic.
- Elemental analysis shows <100 ppm Ni
- Undetectable PCBs or chlorocarbon levels in as-made material
- We are producing >250 g/run
- TCLP test shows < 300 ppb of leachable Ni

Carbon Materials: TEM

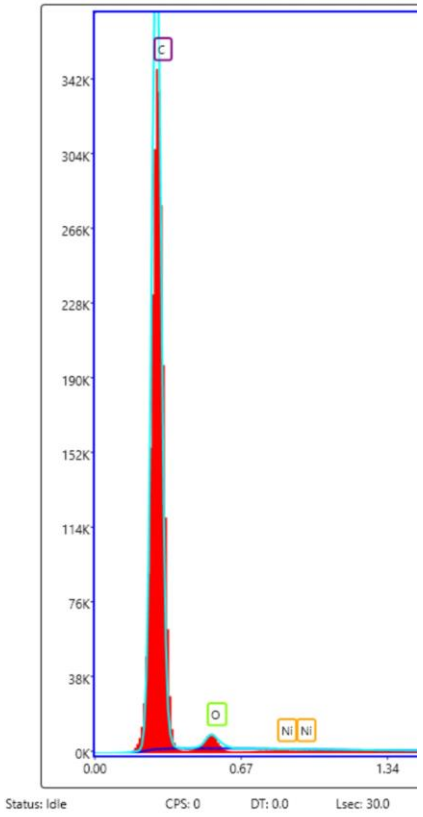


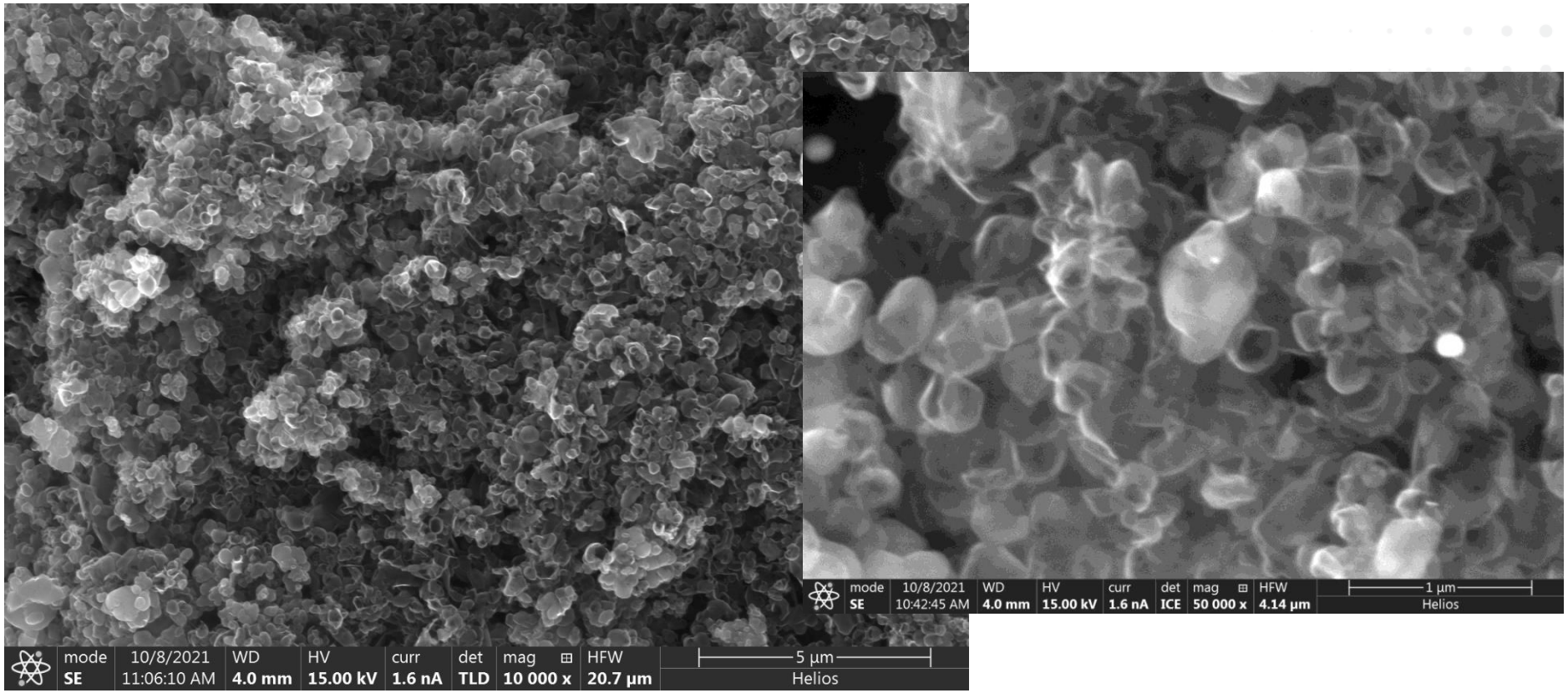
before



after

Carbon Materials: SEM



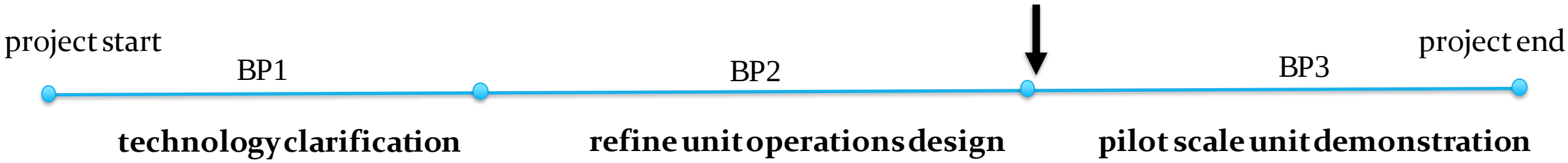


Carbon is homogeneous, mostly comprised of ~250 nm hollow spheres; undetectable metals by EDS

T2M

Our goal is to commercialize the ETCH Process by:

- Enter partnership agreements with key industrial stakeholders
- Technology demonstration of the uniqueness and innovativeness of ETCH Process
- R&D of the ETCH Process to build pilot plant
- Build engineering staff to help design and build plants for customers



- Finalizing a $6 million investment
- Working with partners for larger scale demonstration projects (100-1000 mt/yr)